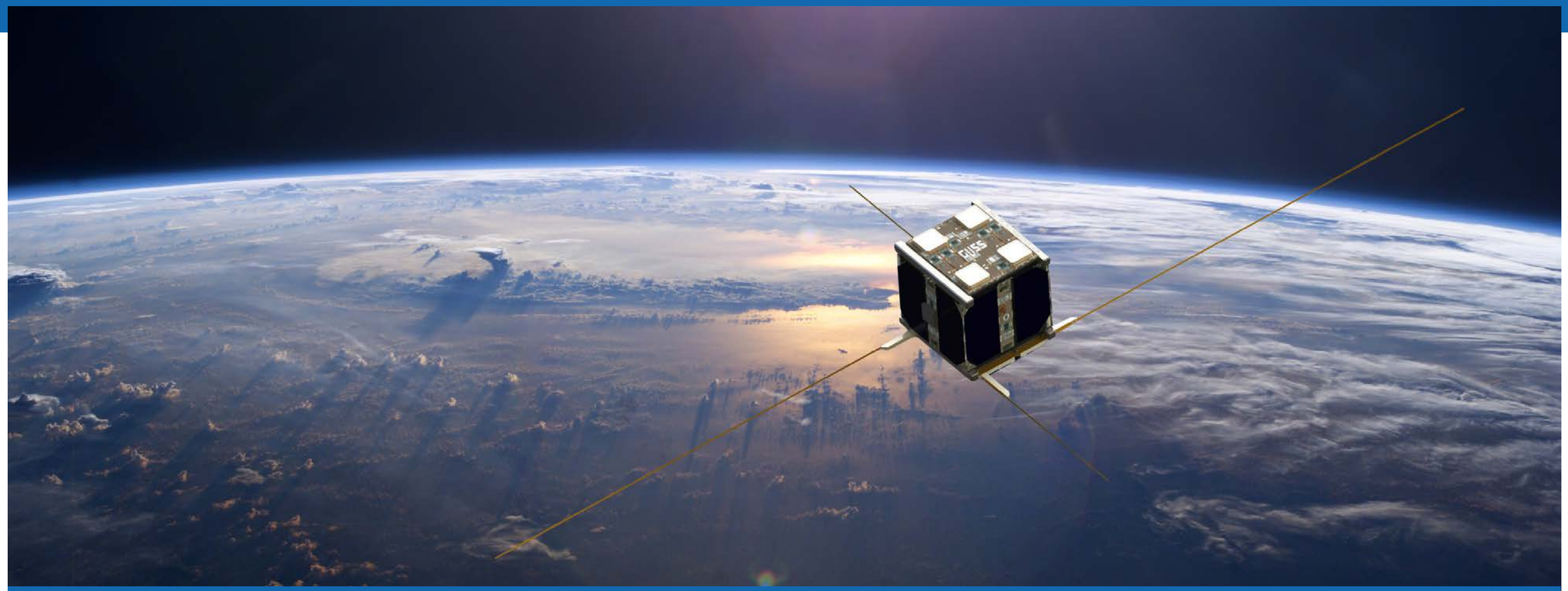


Cube Satellites: CubETH and Astrocast

M. Rothacher and many partners

DGK/SGK/ÖGK-Sitzung, Potsdam, 09.11.2017

Outline

- Motivation and Vision
- CubETH: Original Cube Satellite Mission Concept
- The Astrocast Mission
- Space Environment Tests: Radiation, Temperature, Vacuum
- GNSS Receiver Firmware Modifications
- GNSS Signal Simulator Tests
- Laser Retroreflectors
- Status of the Astrocast Mission

Motivation and Vision

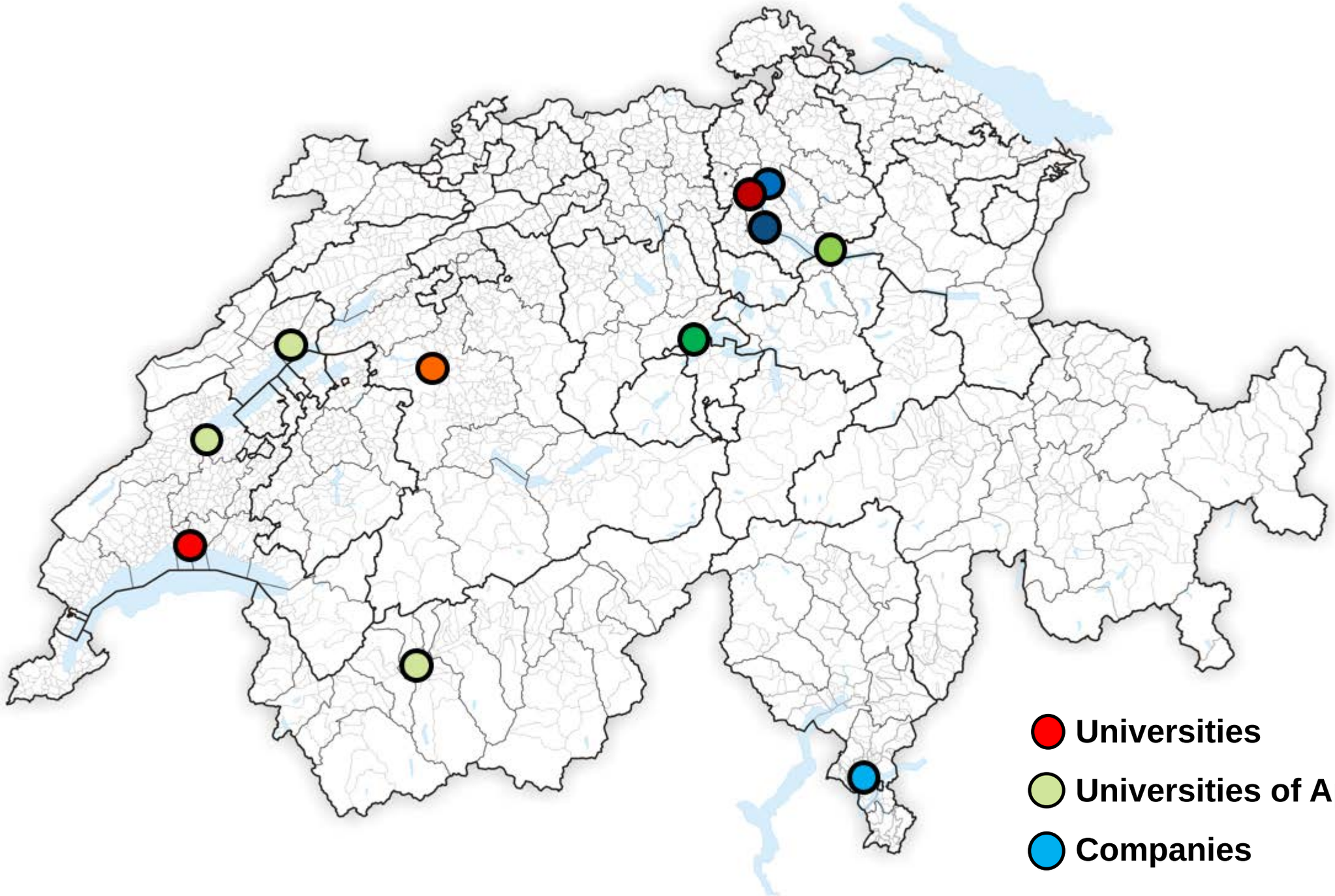
- **GNSS has become a very important tool for satellite missions**
  1. GNSS **precise positioning** (and attitude determination) in space is essential to most Earth observation and science missions
  2. GNSS for **time synchronization** in space (e.g. ACES)
  3. Space-based **Earth observation** based directly on GNSS sensors

     Water vapor, electron content in ionosphere, gravity field, ocean surface, tsunami early warning

- **Vision:** perform these GNSS measurements with **very efficient, small, low-cost, low-power GNSS receivers** (miniaturization, small is smart)
- Geodetic type space receiver ~ **€ 500'000, 3 kg, 15 W , 30 cm**
- u-blox low-cost receiver ~ **€ 200 , 8 gr, 80 mW, 1.5 cm**
- Small satellites/sensors are a must for **future formation flying / large constellations**

CubETH: Movie

CubETH Partners



Partners: Responsibilities

Universities:

ETHZ:	Mission PI, GNSS payload, science software, orbit and attitude determination
EPFL:	Mission management, satellite bus (COM, EPS, CDMS, ADCS, mechanical structure)
AIUB:	SLR tracking, maybe CCD observations (tbc)

Universities of applied sciences:

HSLU:	Payload HW, payload control SW, ground station
HSR:	GNSS antenna design
HES-SO:	Collaboration on satellite bus development

Companies:

u-blox:	multi-GNSS receivers
RUAG:	Support (test facilities, space expertise, reviews)
Saphyrion:	Support (receiver technology, satellite bus)

External Support and Collaborations

• Swiss Space Center	Support to EPFL
• Skyguide	GPS signal simulator for tests
• Institute of Geodesy, Leibniz University Hannover or GEO++ (tbc)	Antenna phase center calibration
• DLR Oberpfaffenhofen	GNSS signal simulator tests
• WG “SLR to small satellites”, (ÖAW Graz, TU Graz, GFZ Potsdam, TU Berlin, DLR and ETHZ)	Corner cubes, orbit validation by SLR
• RUAG Space, Gothenborg, Sweden	Review of GNSS antenna design

Financial philosophy: each institution is financing its own studies, developments, man power and material

Astrocast and its GNSS Payload

Astrocast:

- 3U cubesat for M2M communication
- 3-axes stabilized and equipped with a propulsion system
- Constellation with a total of 40 satellites planned

GNSS Payload:

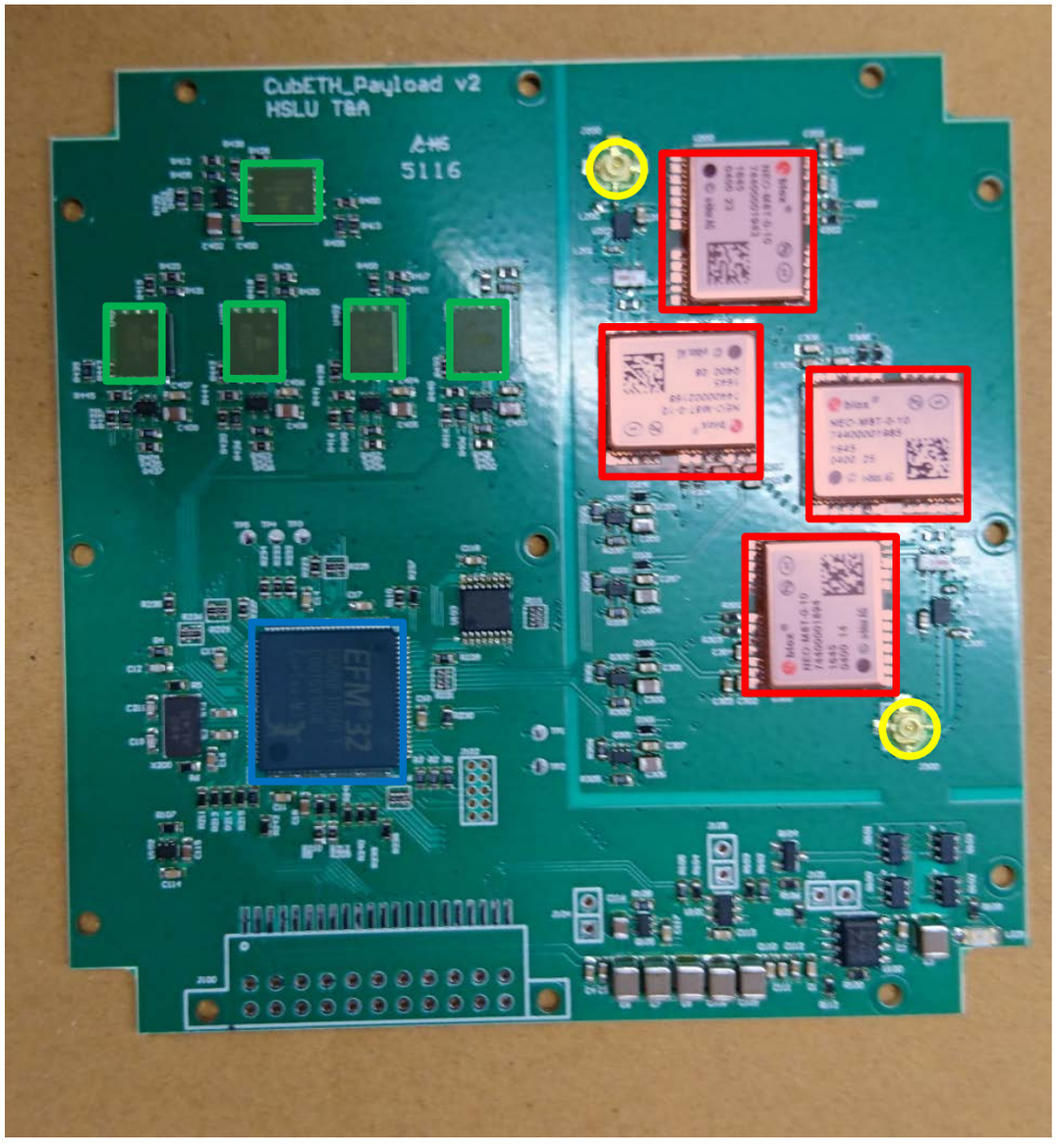
- 4 u-blox NEO-M8T multi-GNSS single-frequency receivers
- Connected to 2 antennas (nadir, side-looking; redundancy)

Mission Goals with GNSS Payload

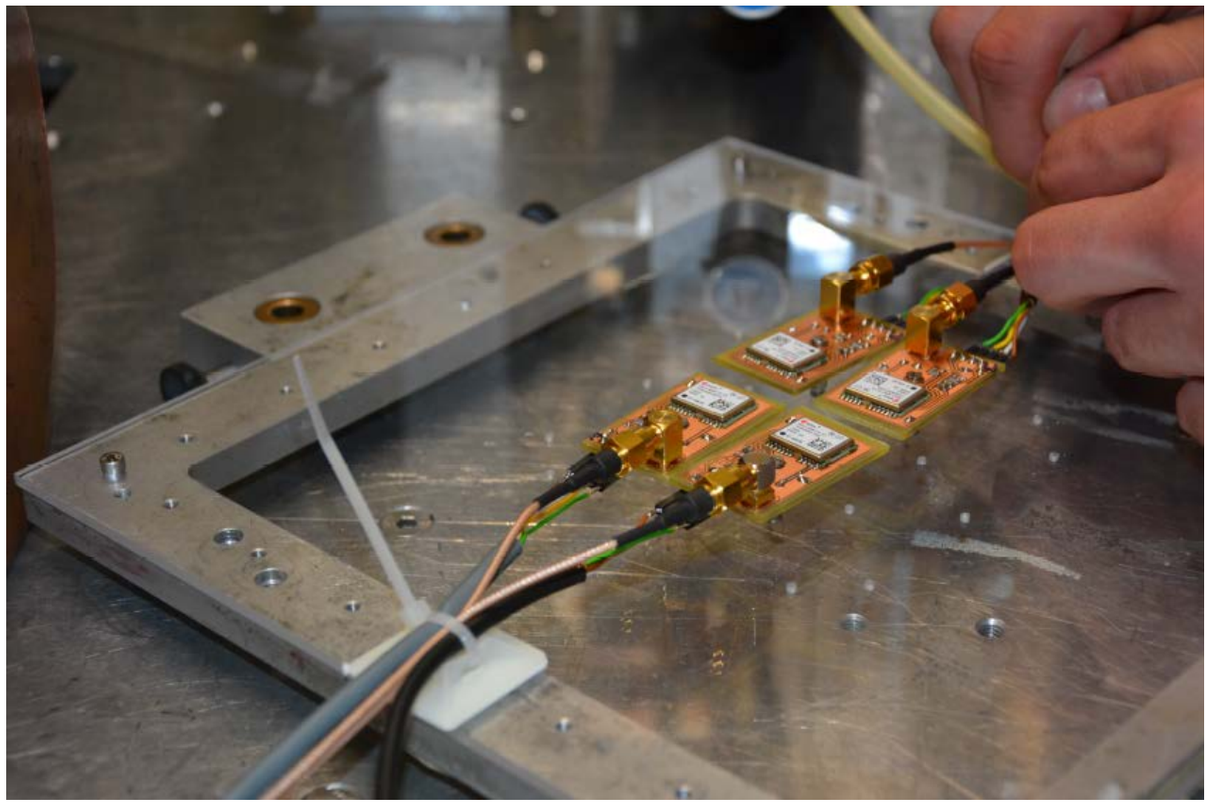
- First **multi-GNSS receiver** in space: GPS, GLONASS, Galileo, Beidou, QZSS
- **Precise orbit determination** with COTS-based **single-frequency receiver**
- **Compare the orbits** derived from different GNSS
- **Validation of the orbit accuracies with SLR**
- Validation of propulsion system
- Constellation maintenance
- Sidewise-looking antenna: S/N analysis at low elevations (occultation scenario)
- Short baseline in space: antenna phase center calibrations, multipath

GNSS Payload Board

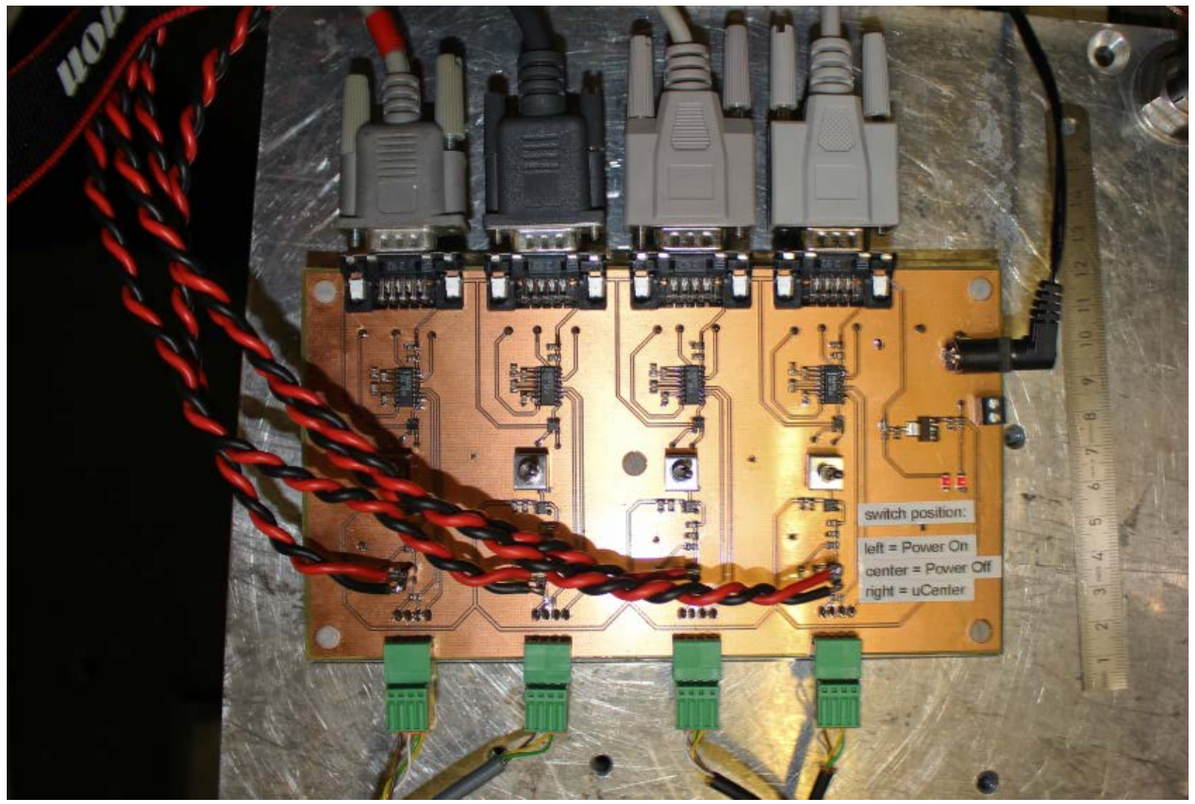
- 4 u-blox single-frequency multi-GNSS receivers (low-power, low-weight, inexpensive; redundancy)
- 2 antenna HF inputs (top, front antenna), two receivers per antenna
- 2.5 MB MRAM onboard memory
- ARM Cortex-M3 CPU
- Latchup protection
- Major task: space environmental tests (radiation, vacuum, temperature, …)



Irradiation tests of u-blox M8T receivers at Paul-Scherrer-Institute (PSI)
Test setup hardware

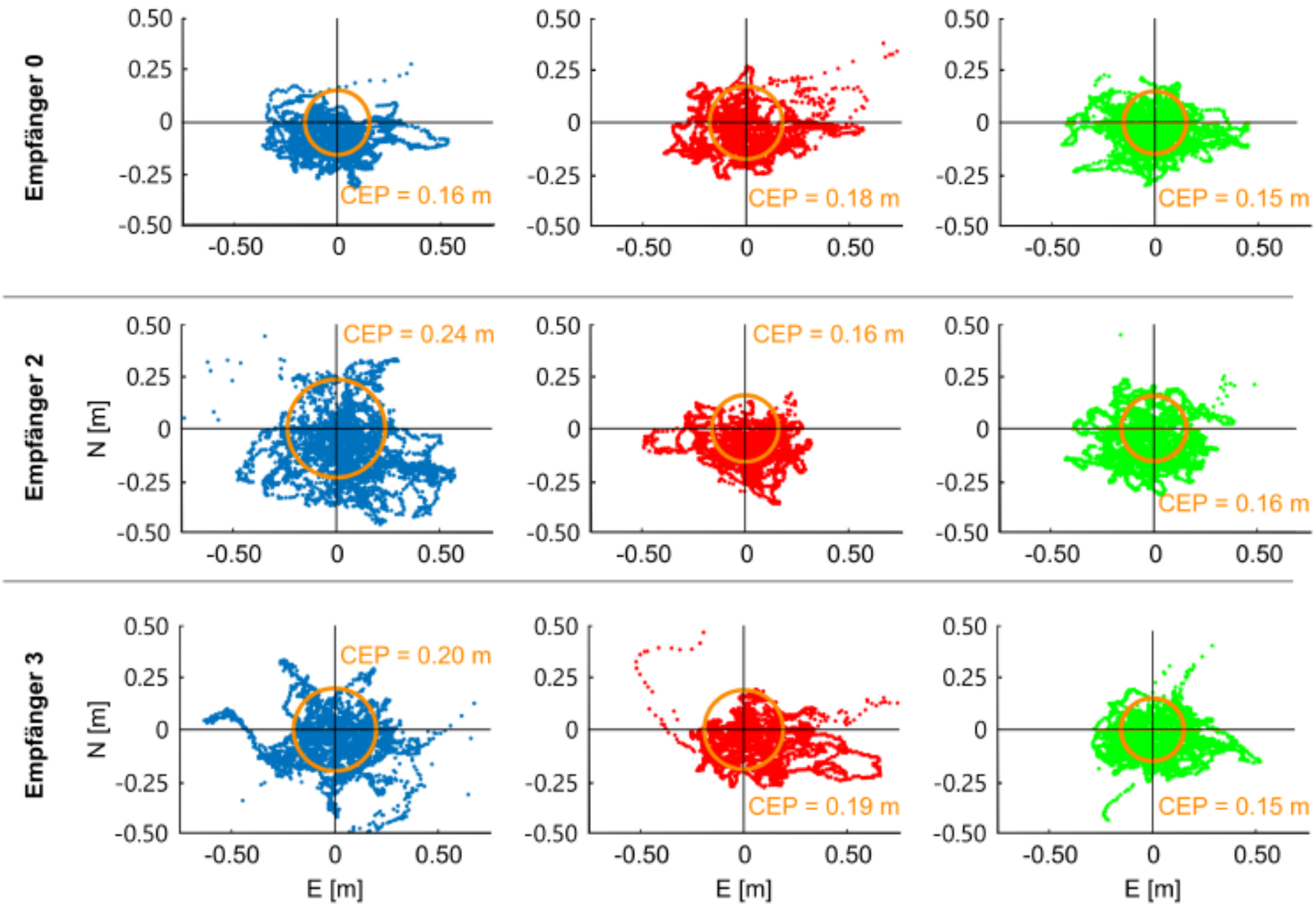


Devices under test



Control board

Irradiation tests of u-blox M8T receivers
Test summary – Quality of position

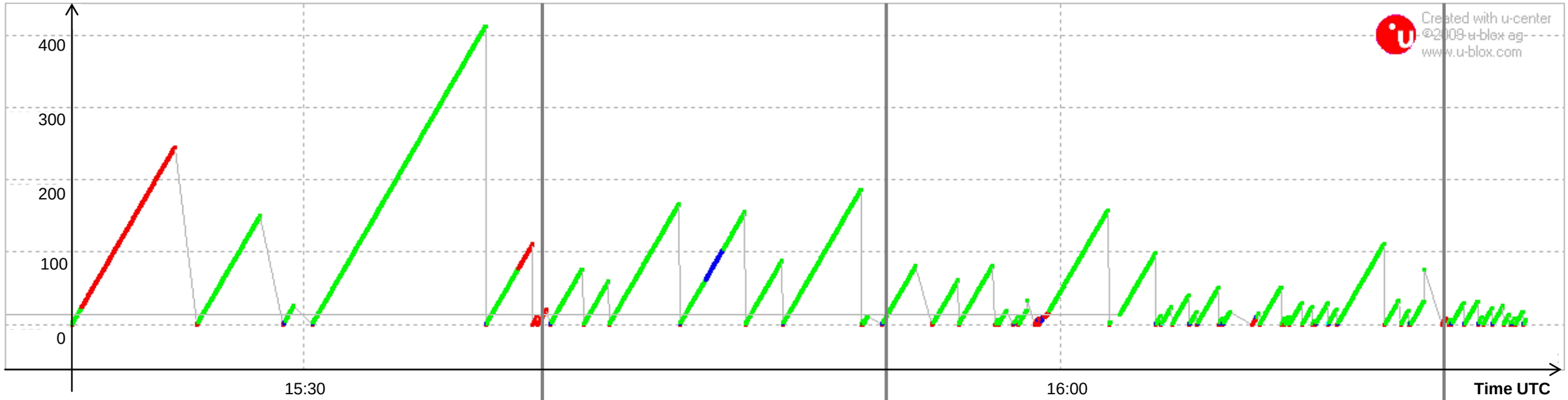


pre-irradiation **1 month after** **2 months after**

Irradiation Tests: Single Events

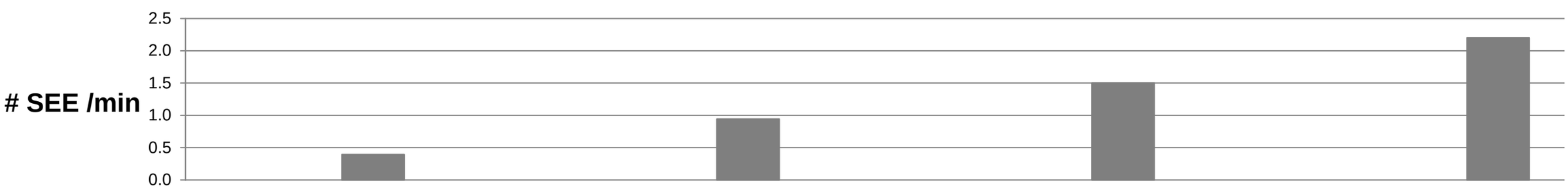
Time since startup / software reset [s]

Energy: 100 MeV



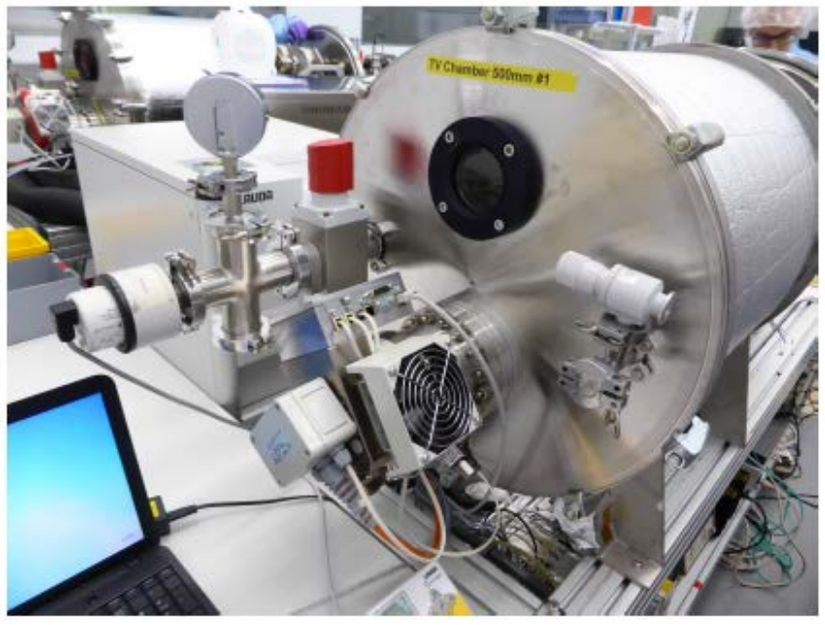
Flux [10^6 p/cm^2/s] **:** 7 14 28 56

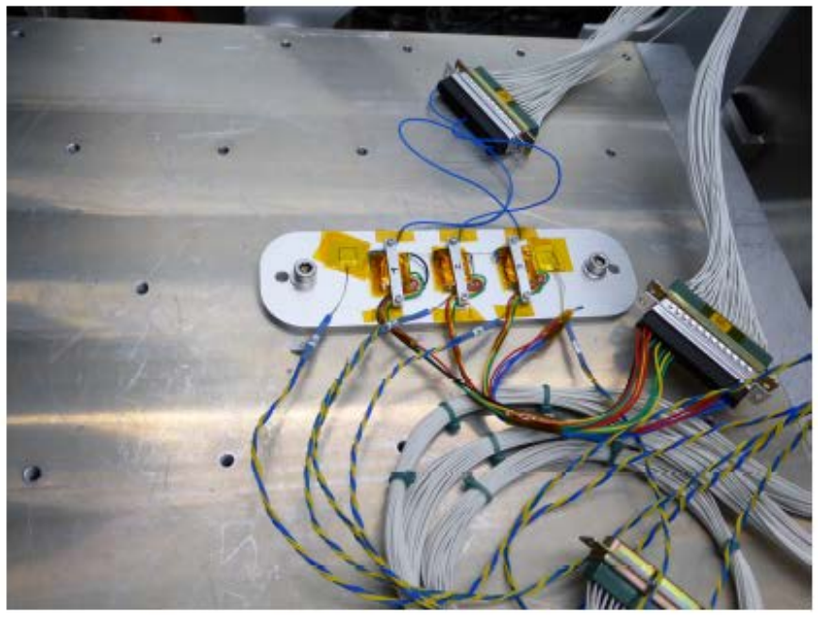
x2 x2 x2

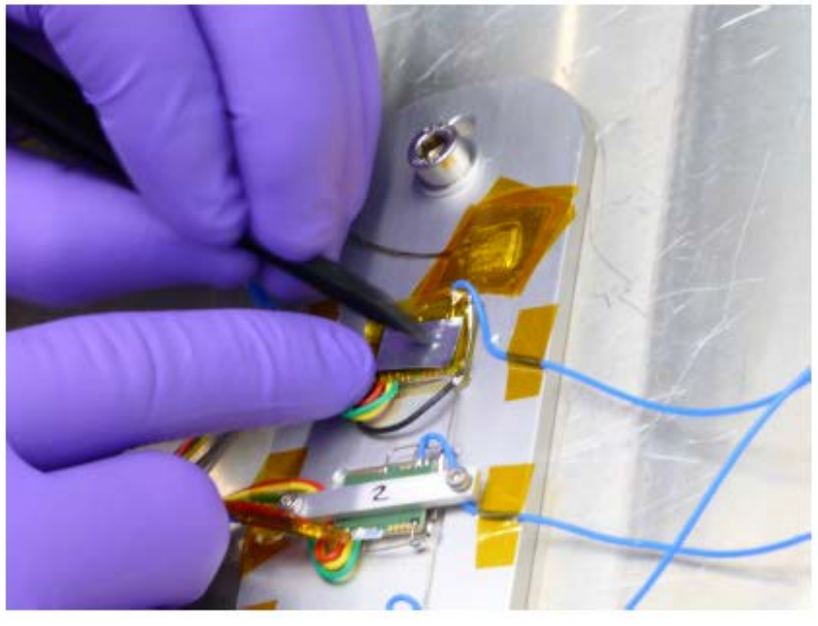


x1.5 x1.5 x1.5

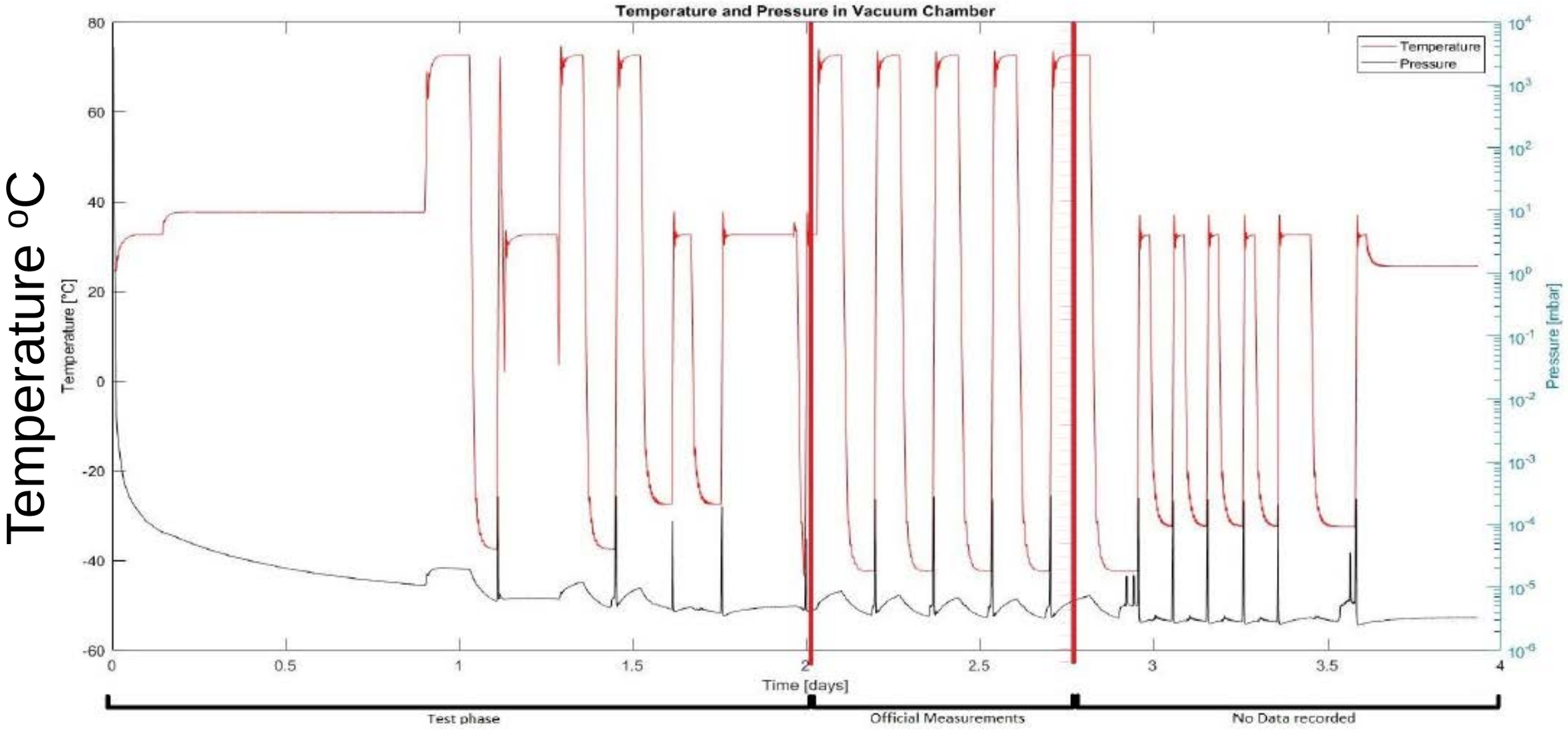
Environmental Test at RUAG: vacuum chamber, temperature cycles







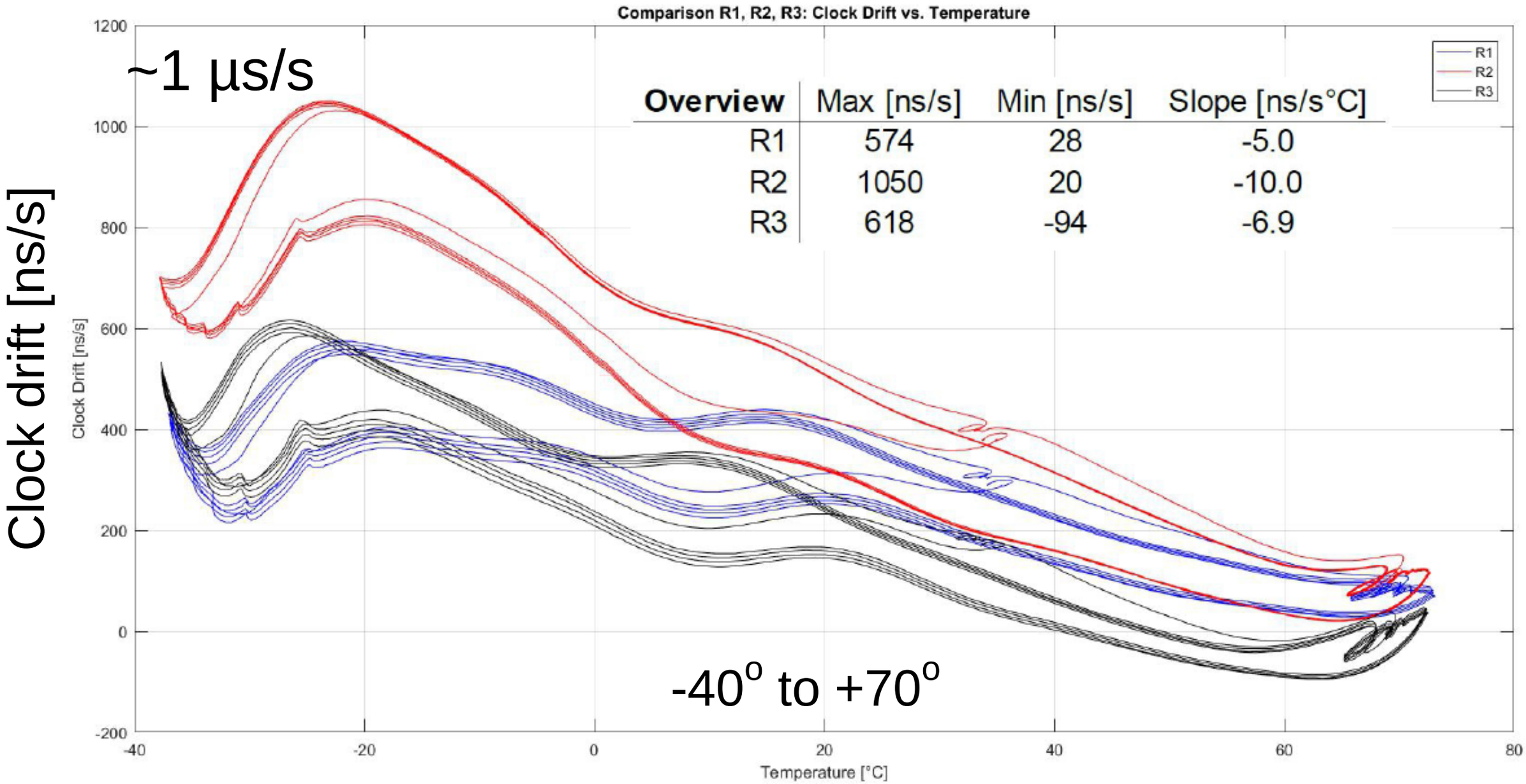
Environmental test
Test cycles (-40° to +70°)



Temperature °C

Test and setup | Measurements | Data loss

Environmental Test at RUAG
Clock drift



Overview	Max [ns/s]	Min [ns/s]	Slope [ns/s°C]
R1	574	28	-5.0
R2	1050	20	-10.0
R3	618	-94	-6.9

Receiver Firmware Modifications (u-blox)

- **Removal of limits:**
  - Removal of the height and speed limits of the firmware
  - Increase of the Doppler search for the GNSS signals (satellite velocity)
- **Real-time Kalman filter:**
  - Improved state propagation in the time update
  - Kepler term, centrigfugal, coriolis (C_{20} only tested)
- **Ionospheric correction:**
  - Modification of the Klobuchar model to fit to Low Earth Orbiters
  - Take into account the height of the satellite
  - Take into account the changed geometry

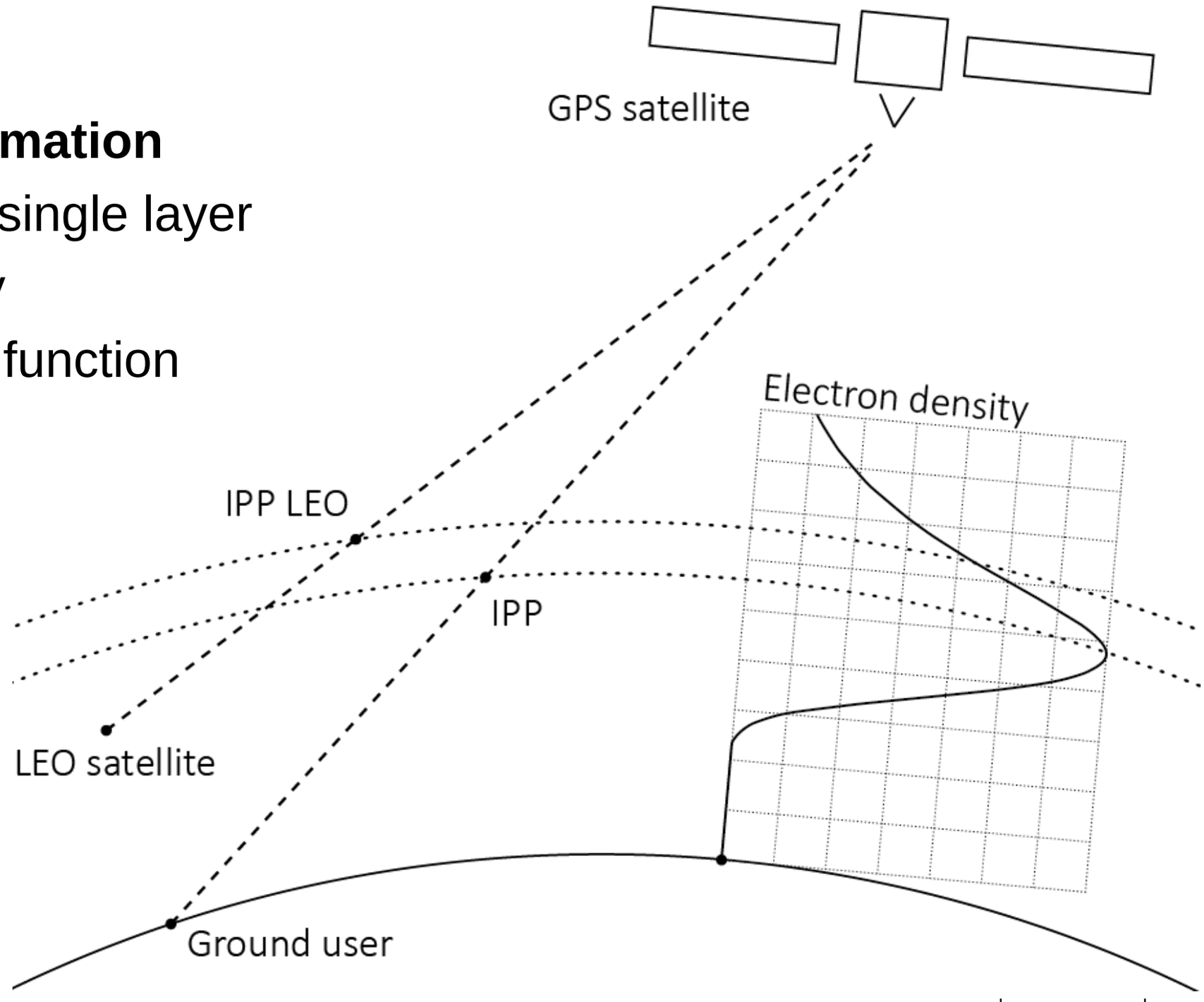
Firmware: Modified Klobuchar for LEOs

Single layer approximation

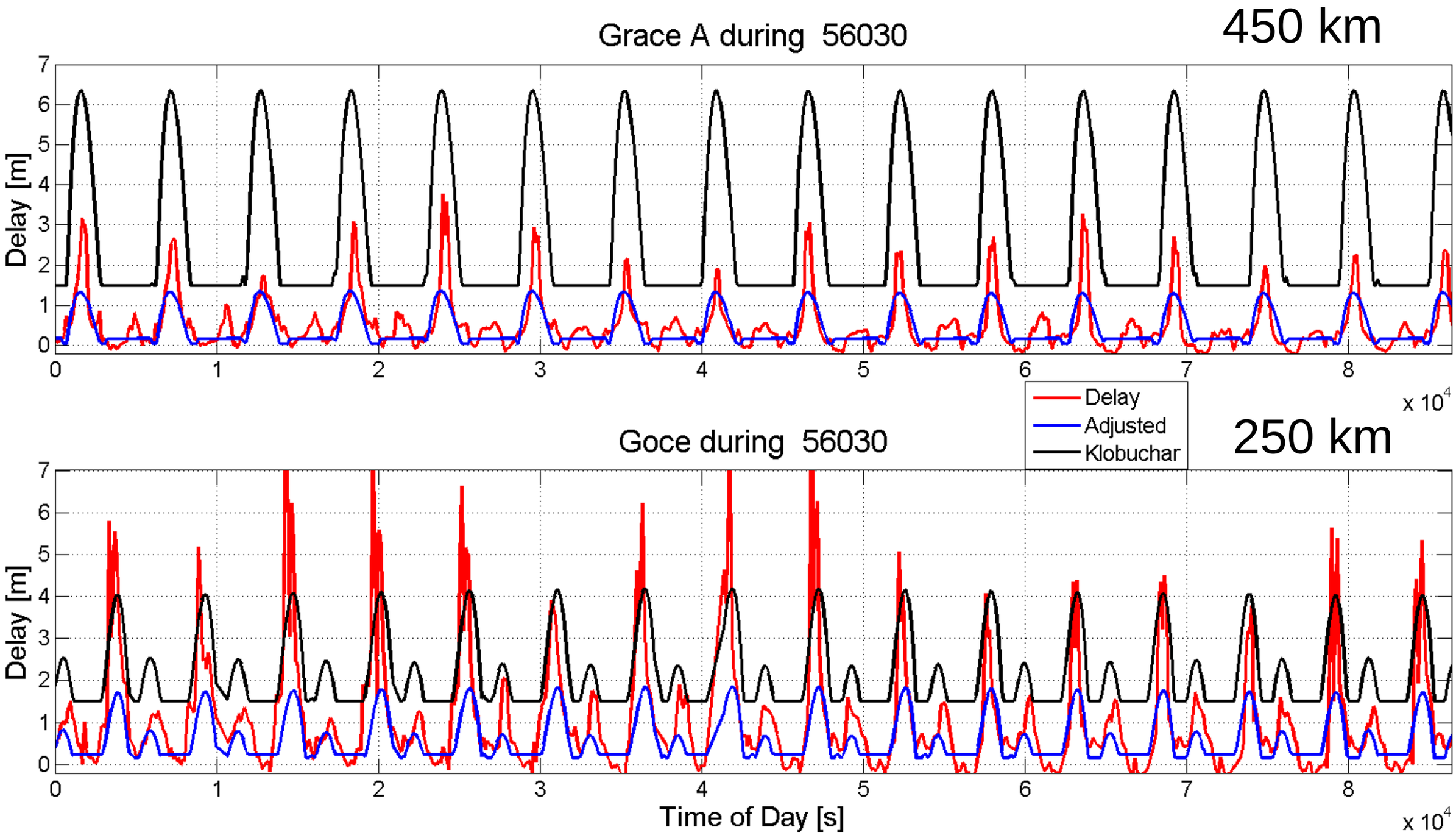
- New height of the single layer
- Modified geometry
- Modified mapping function

Modified total delay

- Assuming a Chapman profile

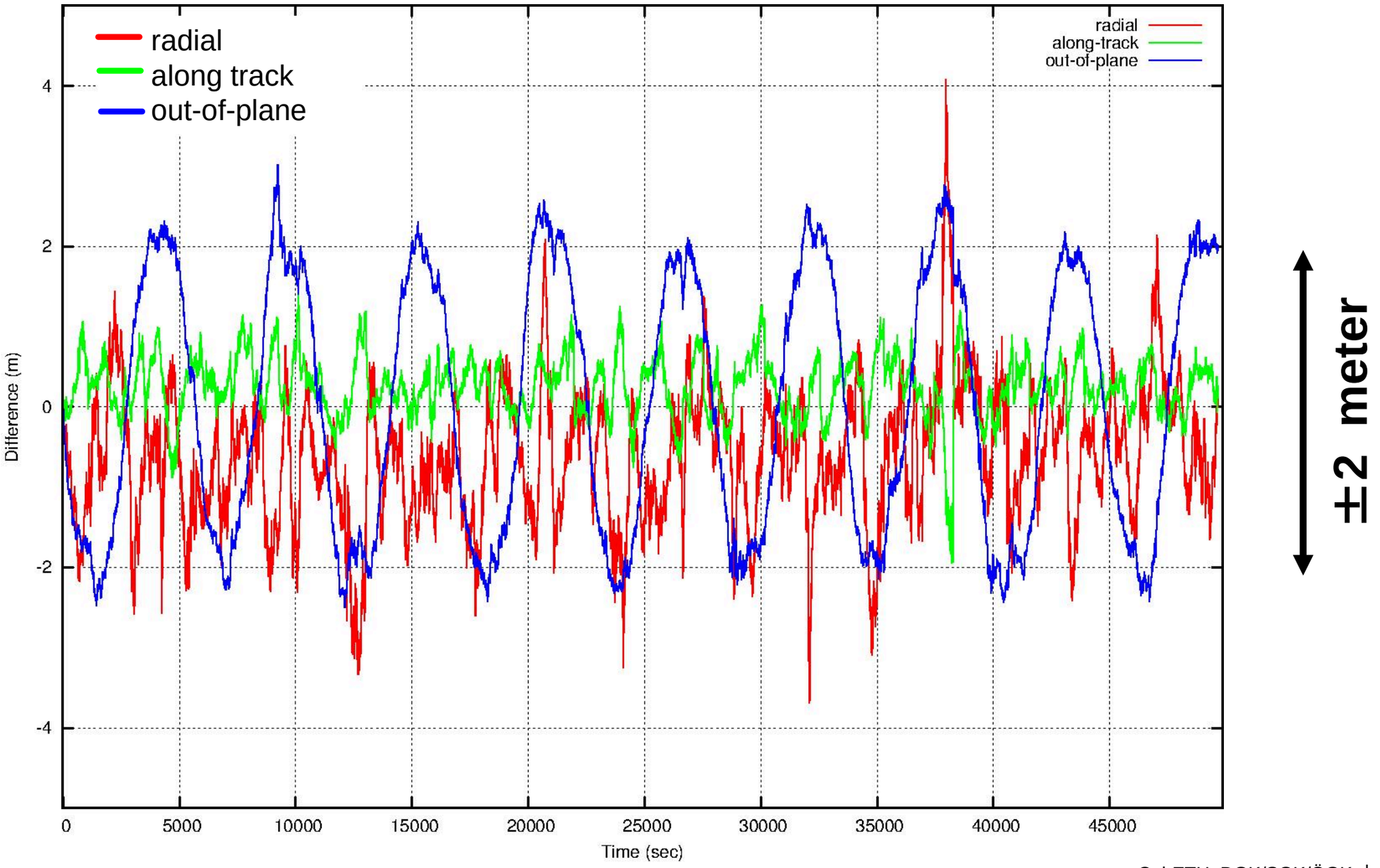


Firmware: Ionospheric Correction (w.r.t real data)



Orbit Determination: GNSS Signal Simulator Tests

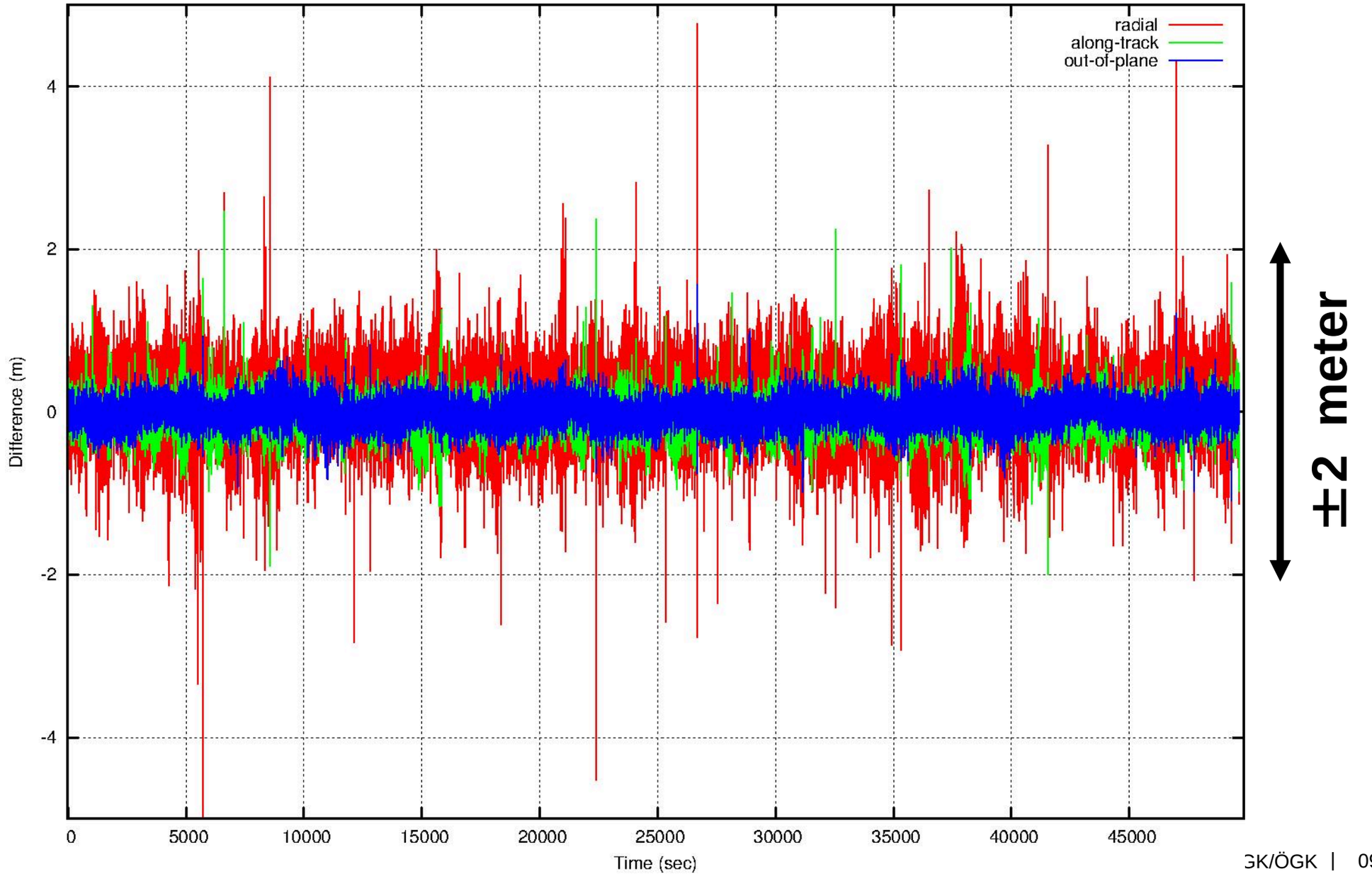
u-blox receiver navigation solution



±2 meter

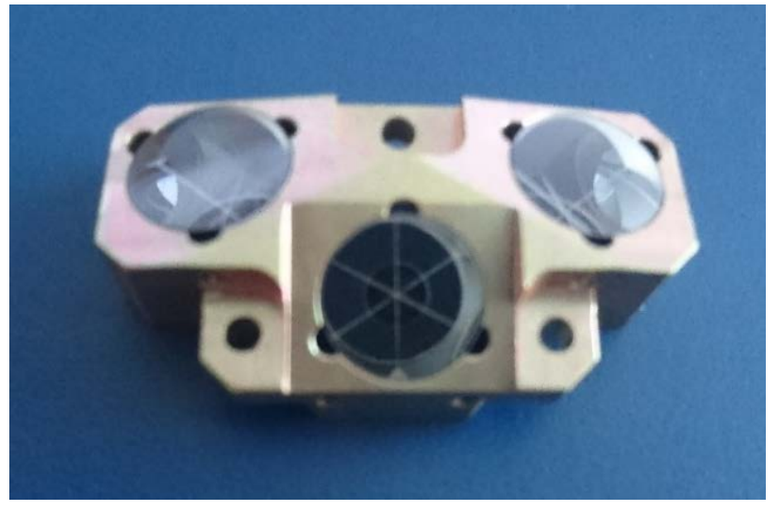
Orbit Determination: GPS Signal Simulator Tests

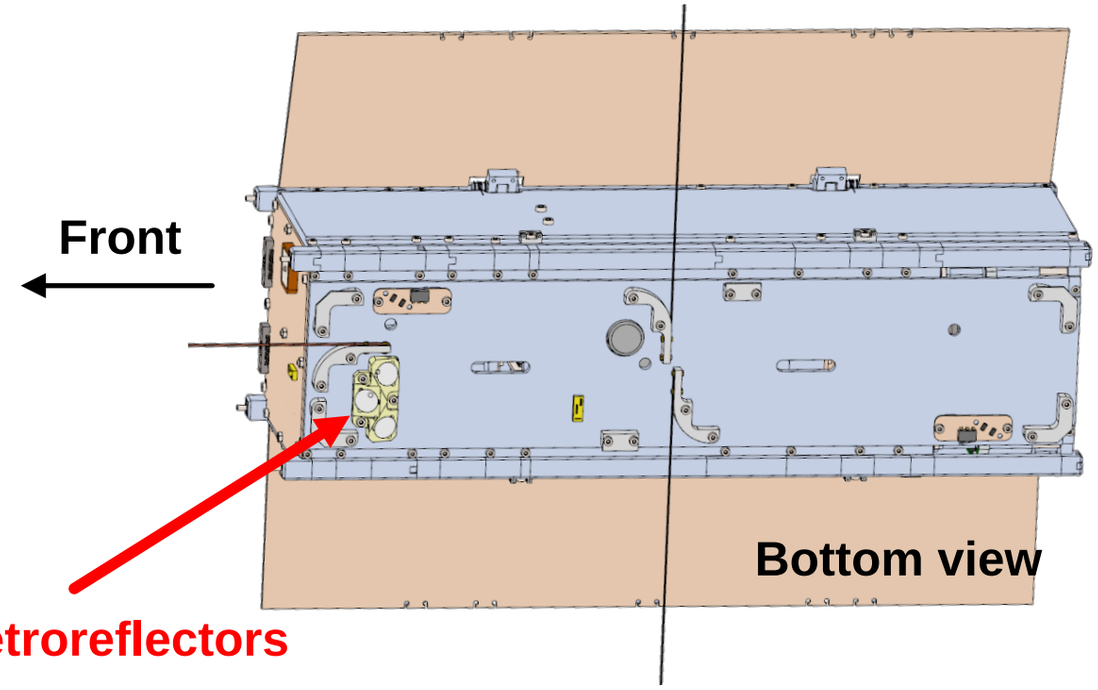
Code solution computed with Bernese out of raw data. The RMS is 0.44 m (radial), 0.21 m (along-track) and 0.15 m (out-of-plane).



Laser Retroreflectors

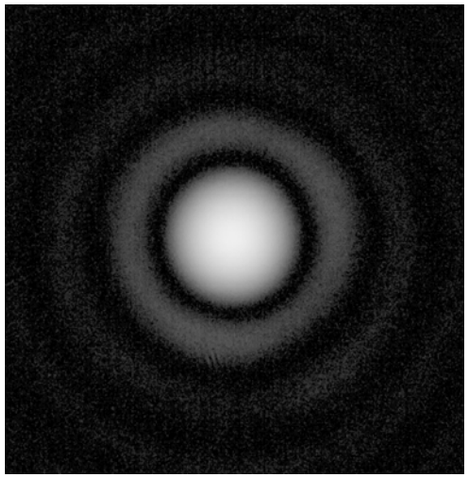
- Mounting for three corner cubes
- One front-looking reflector
- Two side-looking reflectors
- Inclination 20° w.r.t. to surface normal
- 1 cm diameter
- JGS1 optical glass





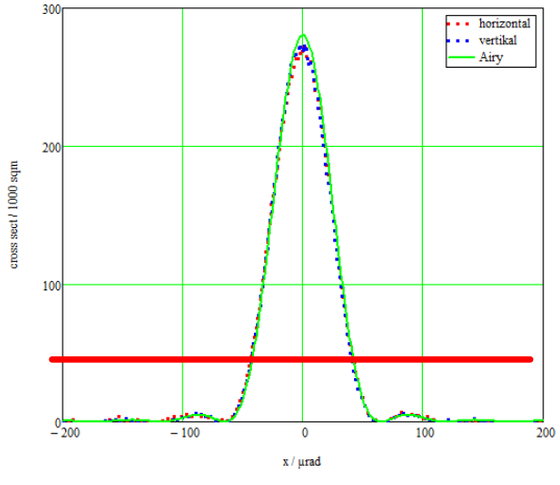
Retroreflector Quality Test (together with Ludwig Grunwaldt, GFZ)

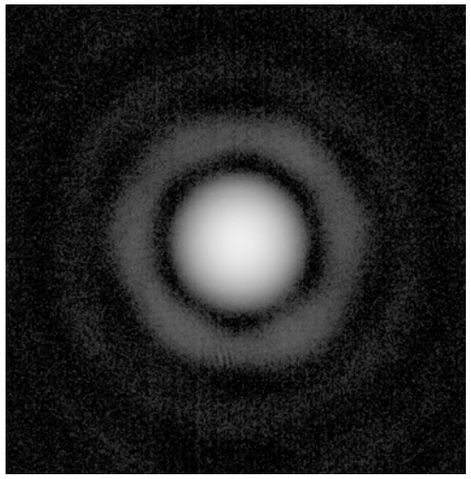
- Laboratory setup at GFZ Potsdam
- Far Field Diffraction Pattern (FFDP) images obtained
- 10 retroreflectors were tested
- Only 1 bad piece detected



$\xrightarrow{100 \cdot \log(A+1)}$

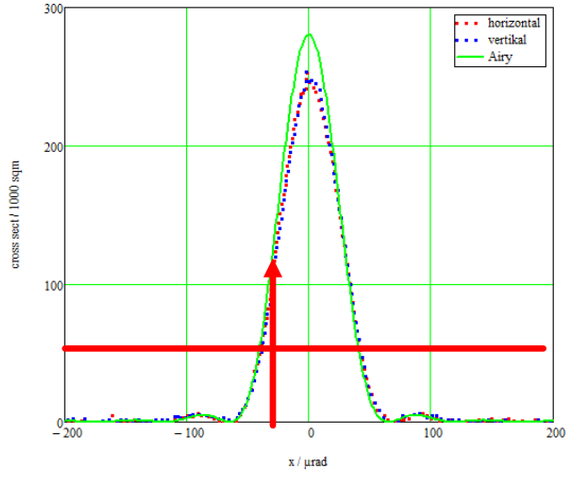
Reference

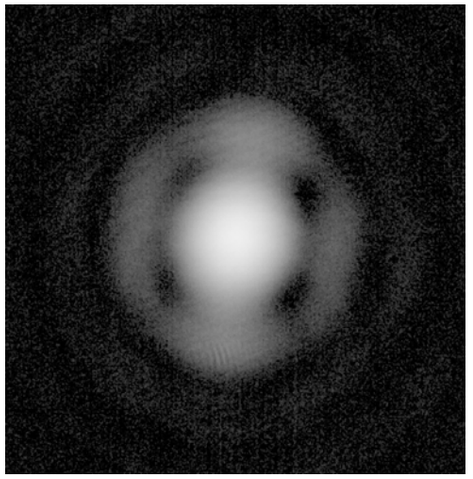




$\xrightarrow{100 \cdot \log(A+1)}$

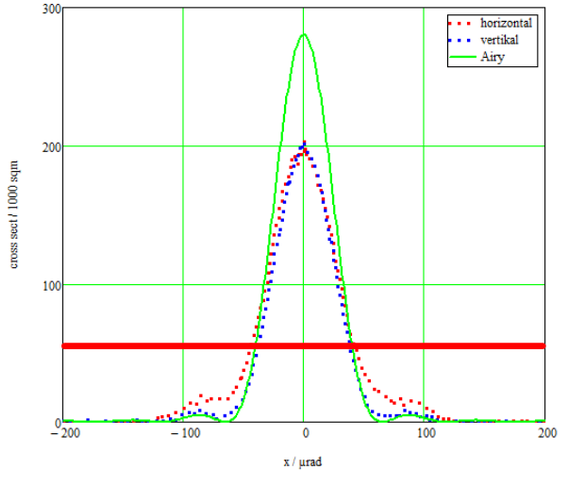
Best case



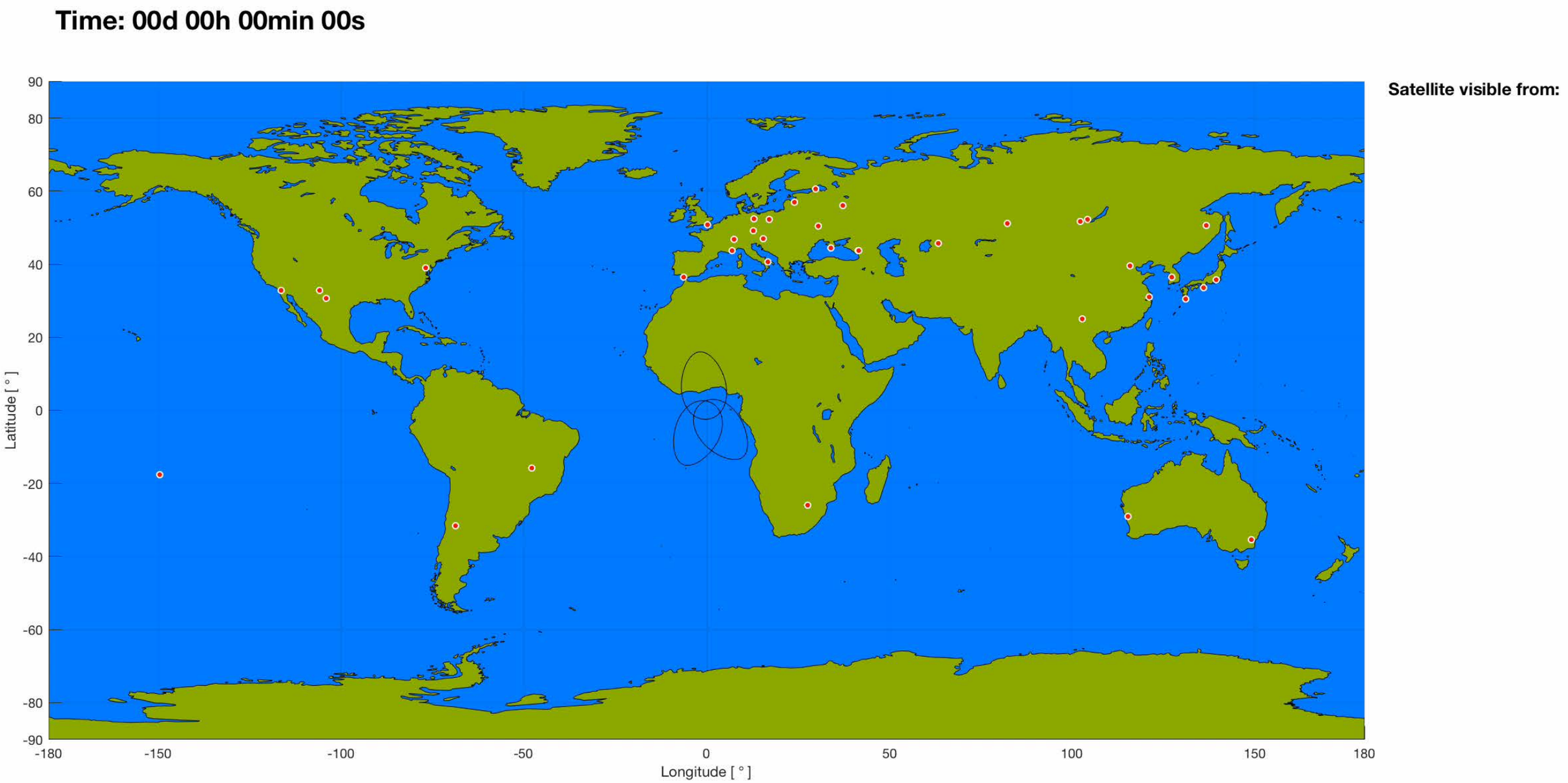


$\xrightarrow{100 \cdot \log(A+1)}$

Worst case

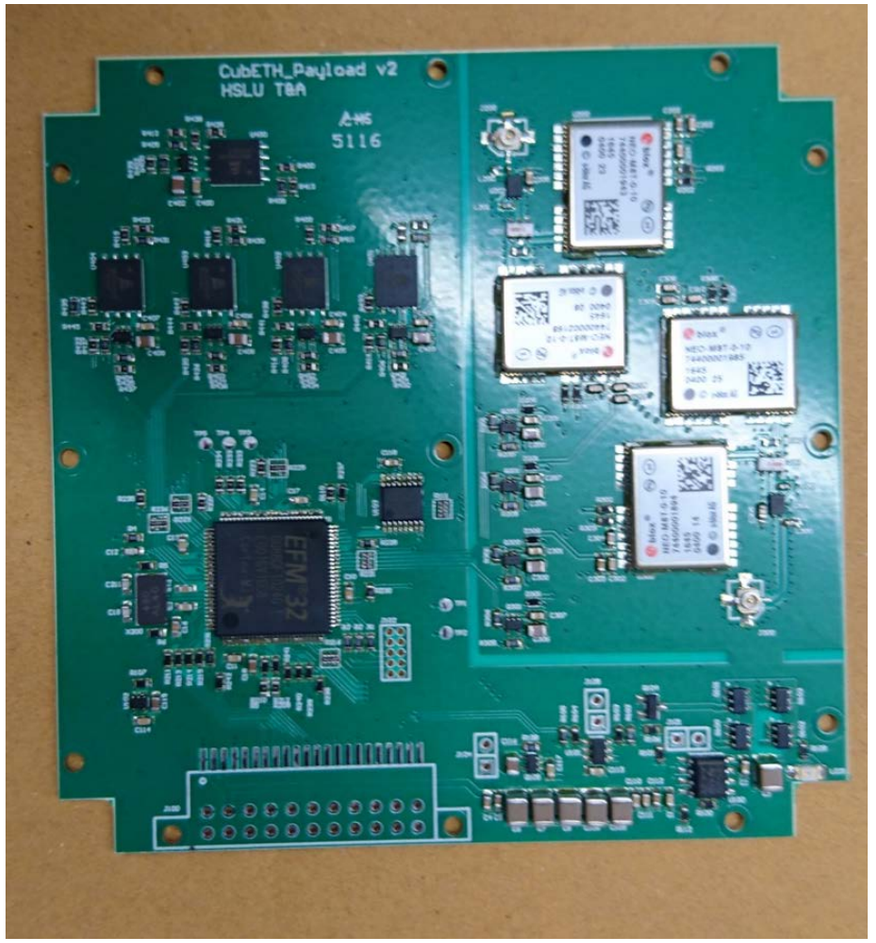


SLR Satellite Visibility Simulation



Status of the Activities

- Payload board ready and under tests
- Upscreening tests (radiation, vacuum, tempe-rapture, …) successfully performed
- Most GNSS signal simulator tests done
- Software developments for post-processing ongoing (graphics linear combination)
- Launch: 07/2018 with Space-X
- **Future** (next steps):
  - **Relative positioning** between satellites (formation flying) with u-blox RTK receivers
  - Scientific exploitation: low-cost **dual-frequency** GNSS/Galileo receivers onboard cubesats (COTS dual-frequency receivers on the way !)



Danke für die Aufmerksamkeit !